

Velocity derivative statistics in the shearless mixing, European Mechanics Society, Euromech Colloquium 501, Mixing of coastal, estuarine and riverine shallow flows, Ancona ,

Original

Velocity derivative statistics in the shearless mixing, European Mechanics Society, Euromech Colloquium 501, Mixing of coastal, estuarine and riverine shallow flows, Ancona , 8-11 June, 2008, G.J.van Heijst, M.Brocchini hosting.
<http://www.euromech.org/colloquia/2008/501> / Tordella, Daniela; Iovieno, Michele. - (2008). (Intervento presentato al convegno Euromech Colloquium 501, Mixing of coastal, estuarine and riverine shallow flows tenutosi a Ancona nel 8-11 June, 2008).

Availability:

This version is available at: 11583/2367684 since:

Publisher:

Published

DOI:

Terms of use:

openAccess

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

Velocity derivative statistics in shearless turbulence

Euromech colloquium 501

Daniela Tordella, Michele Iovieno

`daniela.tordella@polito.it`

Dipartimento di Ingegneria Aeronautica e Spaziale

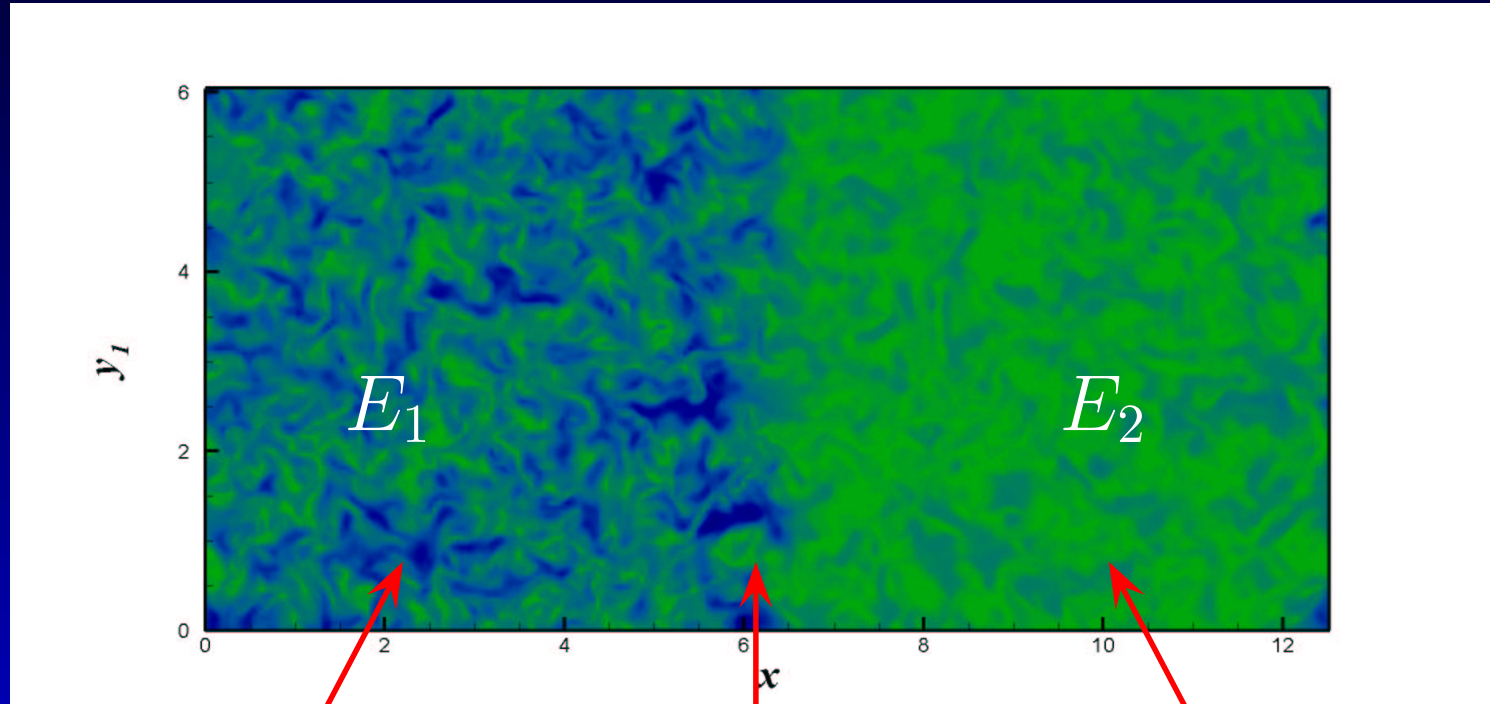
Politecnico di Torino,

Corso Duca degli Abruzzi 24, 10129 Torino, Italy



Turbulent shearless mixing

Ref: *J. Fluid Mech.* **549**, 441-451, (2006).



Run Movie 1-2

1-High energy turbulence

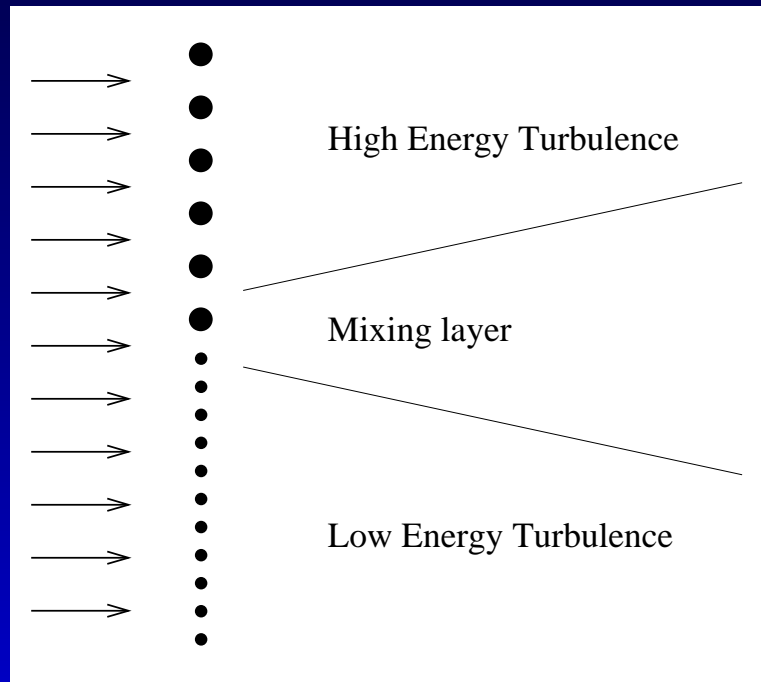
2-Low energy turbulence

Mixing layer

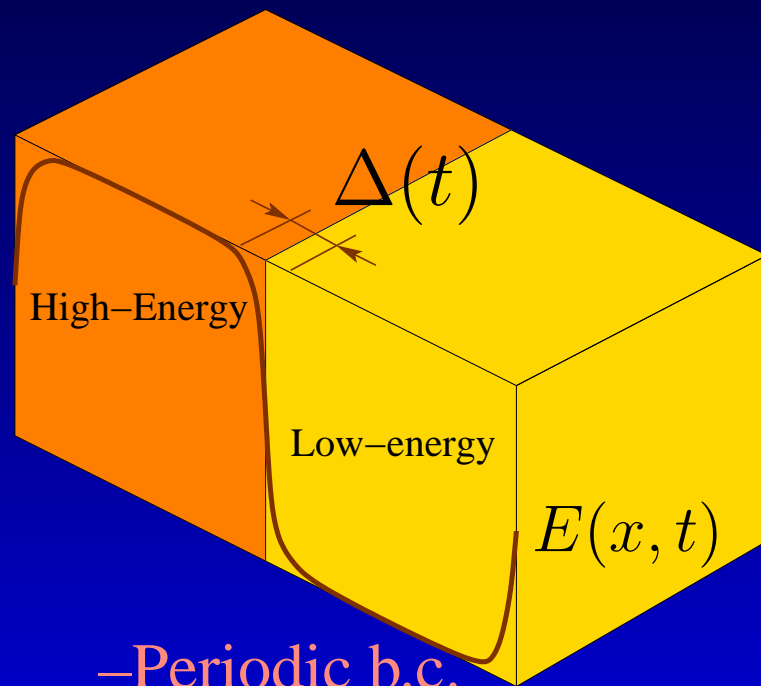


State of the art

- Grid turbulence experiments:
 - ▶ Gilbert *JFM* 1980
 - ▶ Veeravalli-Warhaft *JFM* 1989



State of the art



- Grid turbulence experiments:
 - ▶ Gilbert *JFM* 1980
 - ▶ Veeravalli-Warhaft *JFM* 1989
- Numerical experiments:
 - ▶ Briggs et al. *JFM* 1996
 - ▶ Knaepen et al. *JFM* 2004
 - ▶ Tordella-Iovieno *JFM* 2006
 - ▶ Iovieno-Tordella-Bailey *PRE* 2008)



Main features

- Self-similar stage of decay
- $\overline{u_1^2} \approx \overline{u_2^2} \approx \overline{u_3^2}$
- High intermittency, function of:
 - ▶ gradient of turbulent kinetic energy
 $\Rightarrow \mathcal{E} = E_1/E_2$
 - ▶ gradient of integral scale $\Rightarrow \mathcal{L} = \ell_1/\ell_2$



Method

- We consider two kinds of shearless mixings:
 - with a *uniform scale*: the mixing is generated by the gradient of energy only $\Rightarrow \mathcal{E}$ only parameter ($\mathcal{L} = 1, \mathcal{E} \neq 1$)
 - with a *scale* and *energy* gradient: $\Rightarrow \mathcal{E} \neq 1$ and $\mathcal{L} \neq 1$
- The behaviour of the mixing in the limit of very high energy ratio \mathcal{E} is investigated.
- Method: DNS, parallelepiped domain ($2\pi \times 2\pi \times 2n\pi, n = 2$ and $n = 4$), $Re_\lambda = 45$ and 71 , LES, same domain and $Re_\lambda = 44 - 450$



Velocity statistics

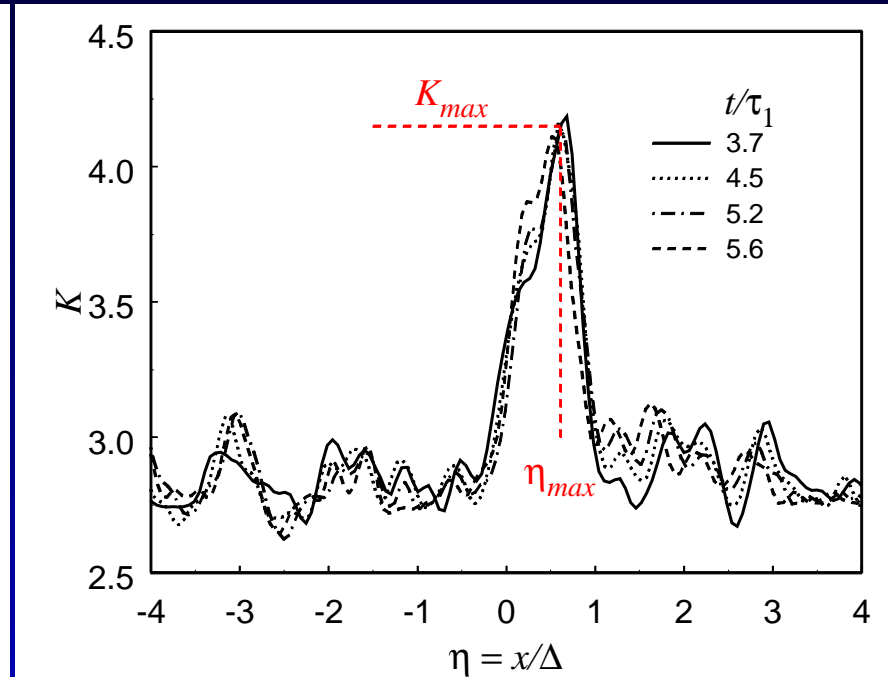
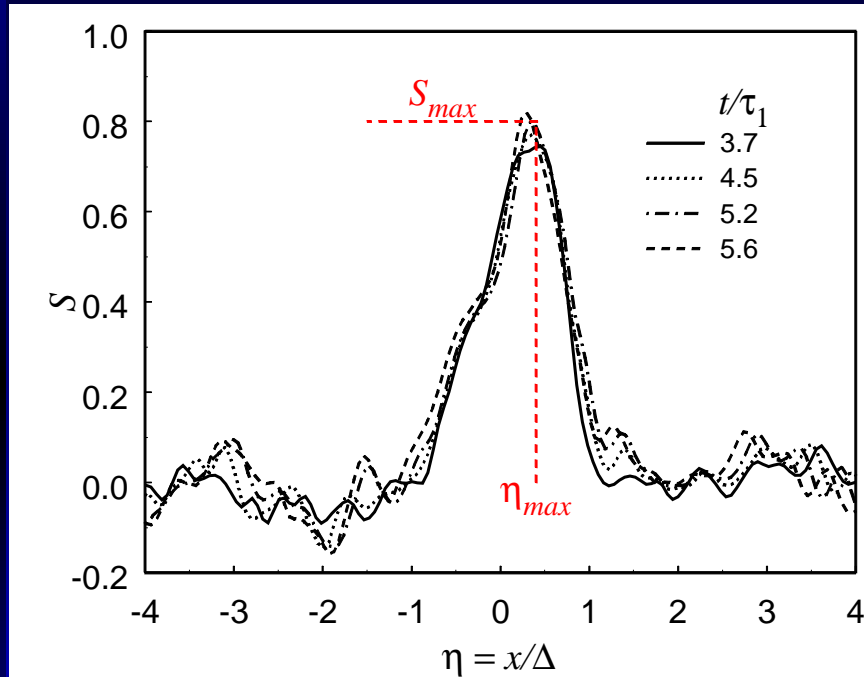
- No shear \Rightarrow no kinetic energy production,
- The mixing is intermittent even if no gradient of scale is present (*PRE* 2008)
- Intermittency is (*JFM* 2006)
 - ▶ *ENHANCED* if the energy gradient is concurrent with the integral scale gradient ($\mathcal{L} > 1$)
 - ▶ *REDUCED* if the energy gradient is opposite to the integral scale gradient ($\mathcal{L} < 1$)
- Self-similar stage of evolution



Intermittency - $\mathcal{E} = 6.7$

$$S = \overline{u^3} / \overline{u^2}^{3/2}$$

$$K = \overline{u^4} / \overline{u^2}^2$$

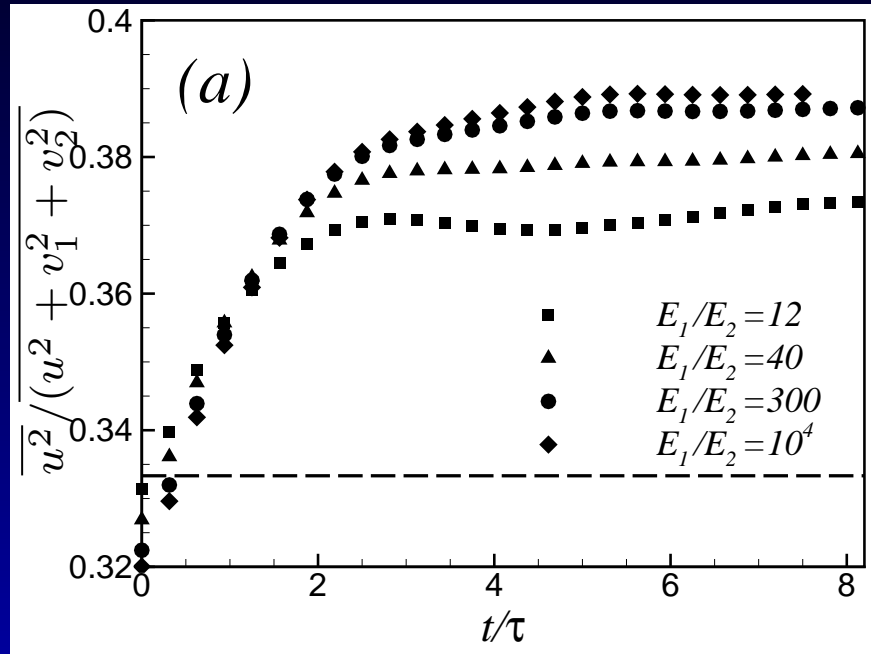


S_{max} , K_{max} = maximum of Skewness and Kurtosis in the mixing layer

η_{max} = position of the maximum in the mixing layer



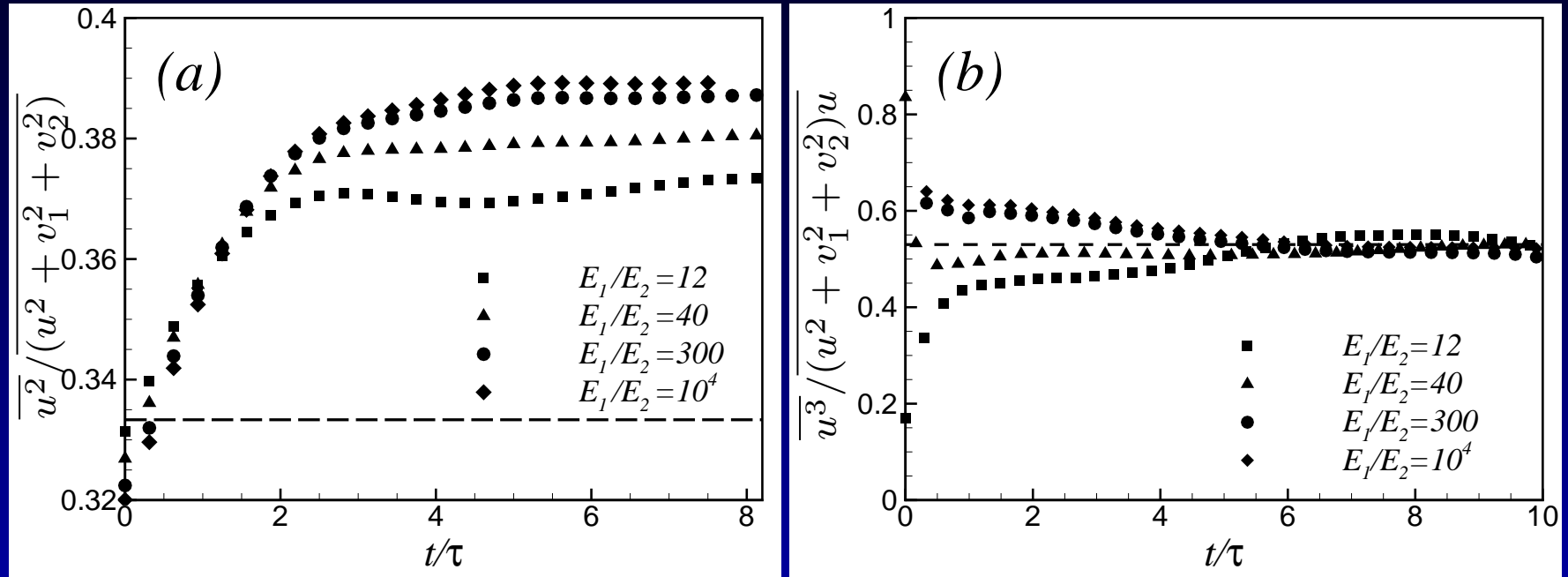
Anisotropy



Left: second order velocity moment anisotropy



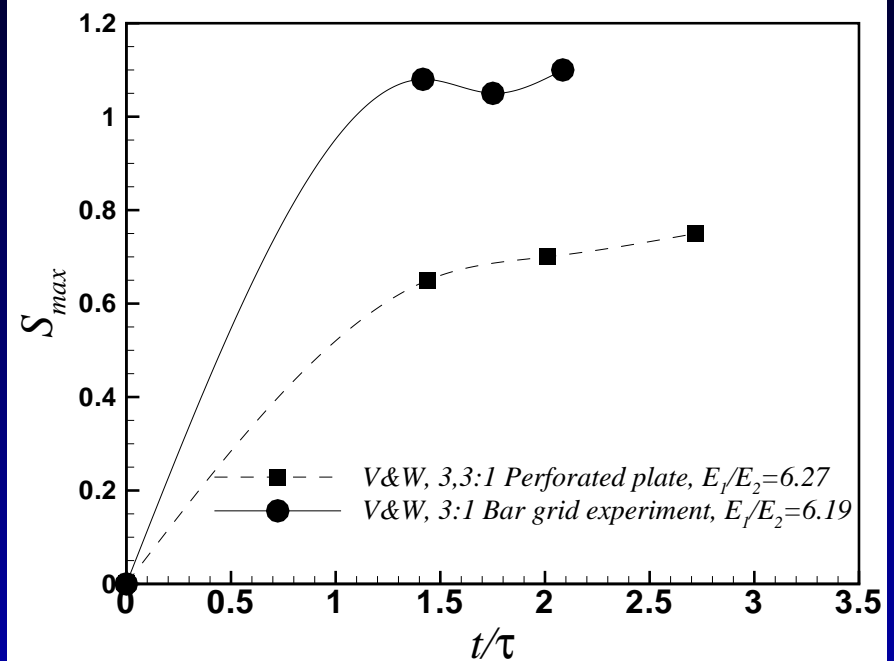
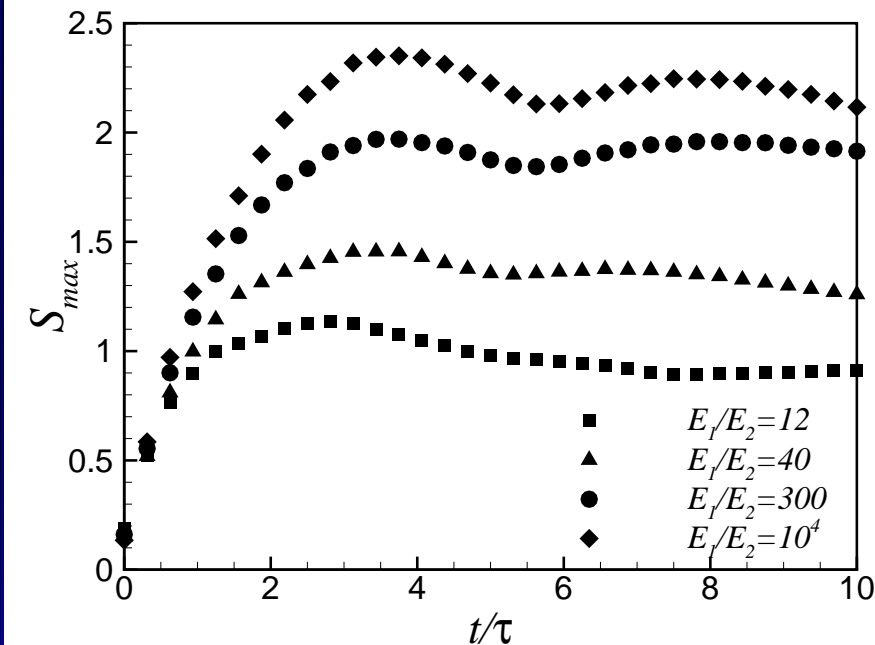
Anisotropy



Left: second order velocity moment anisotropy
Right: third order velocity moment anisotropy



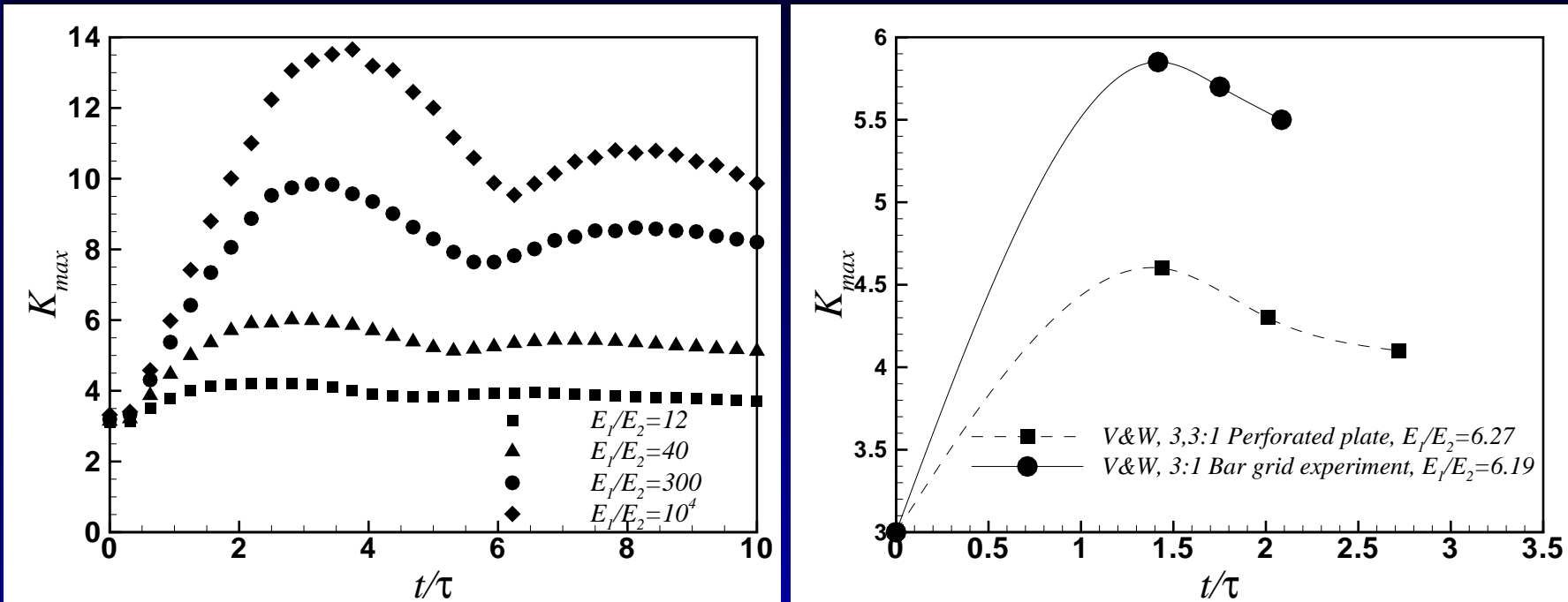
Inhomogeneity: Skewness evolution



Time evolution of the maximum of skewness within the mixing.



Inhomogeneity: Kurtosis evolution

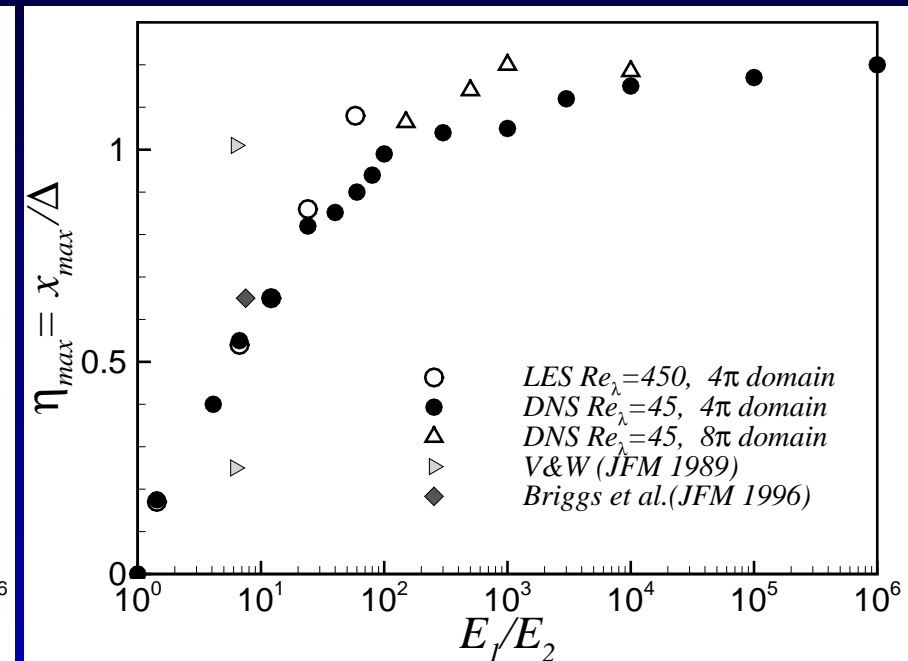
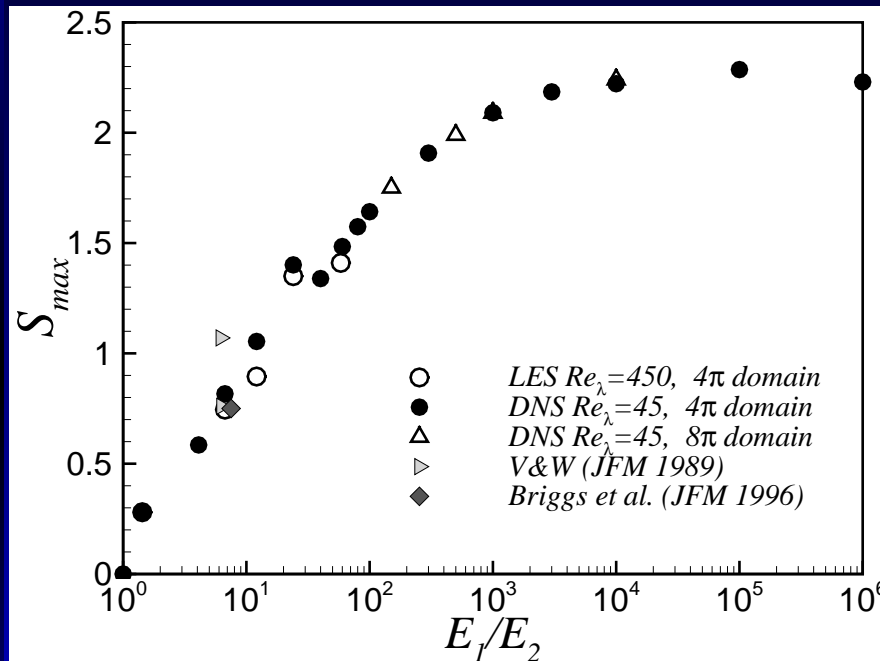


Time evolution of the maximum of kurtosis within the mixing.



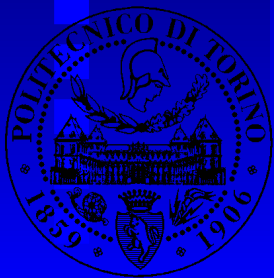
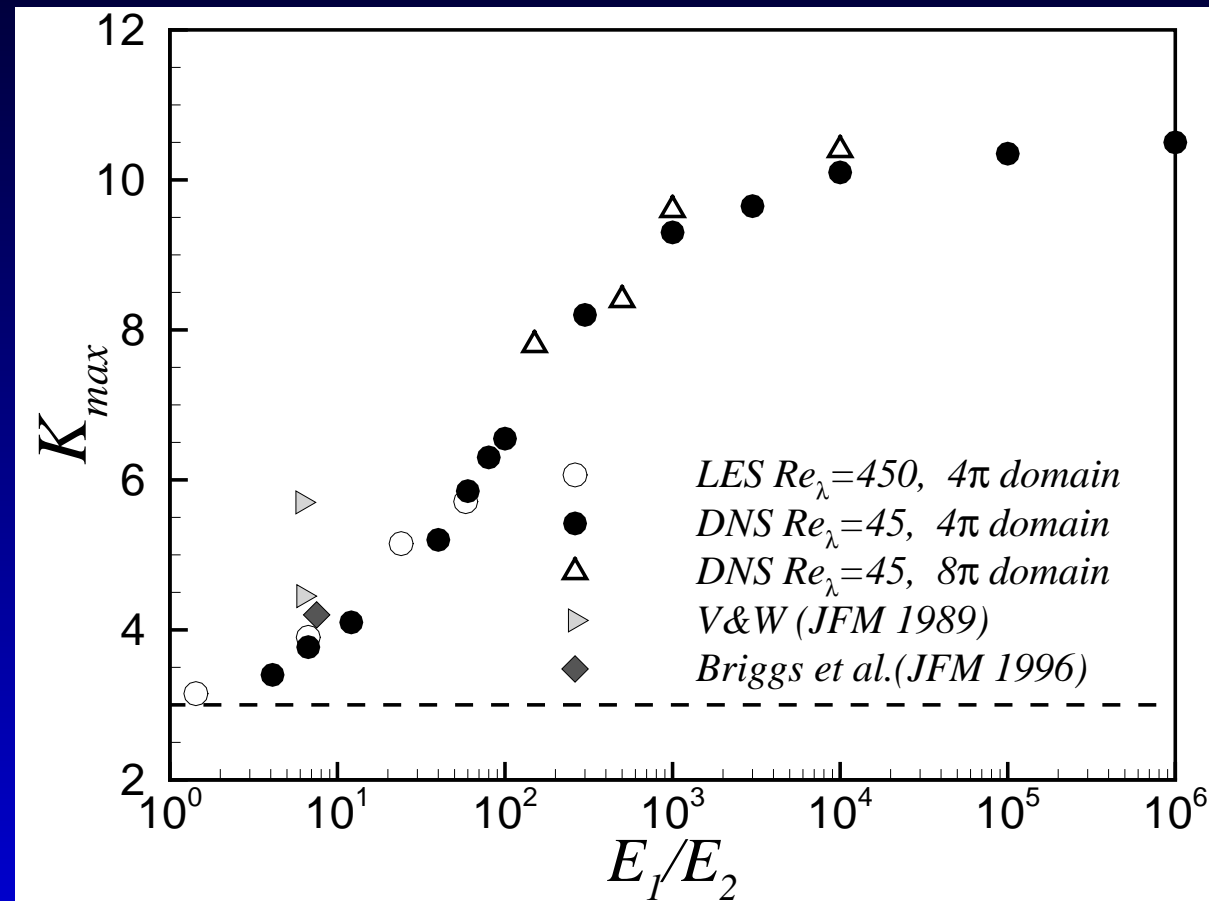
Asymptote for $E_1/E_2 \rightarrow \infty$

Skewness and penetration



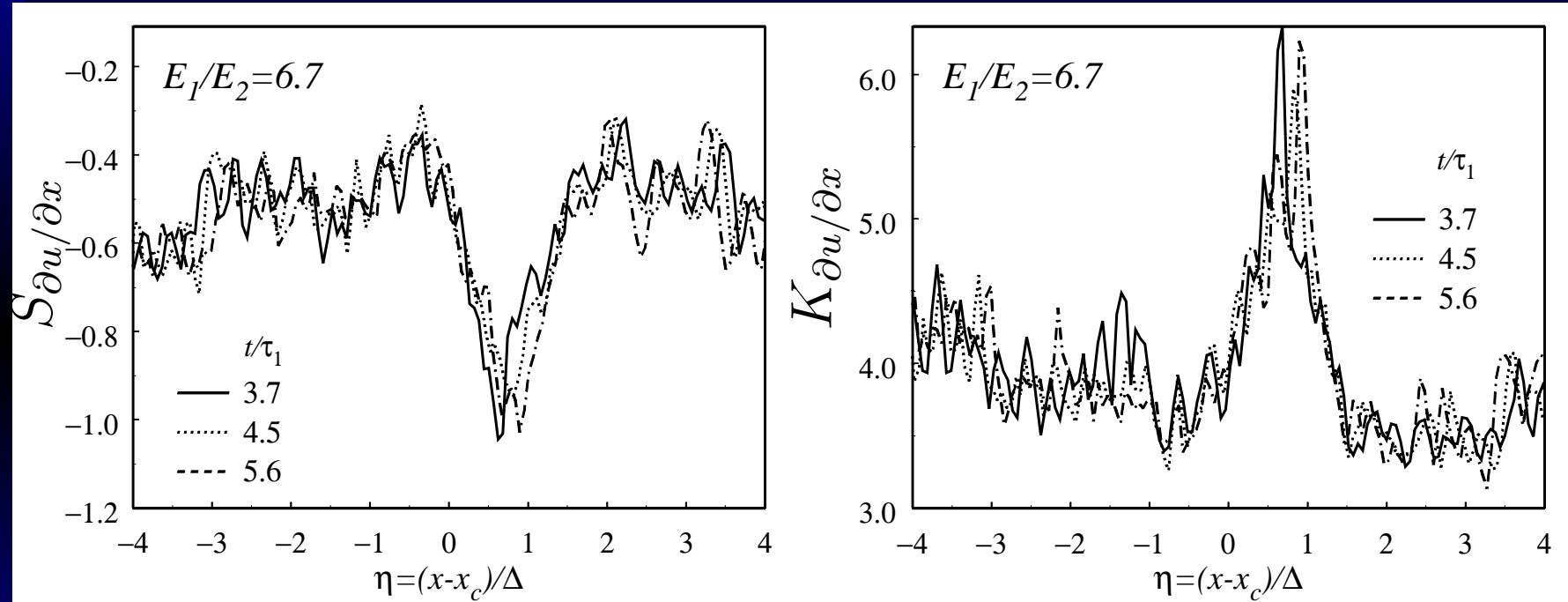
Asymptote for $E_1/E_2 \rightarrow \infty$

Kurtosis



Longitudinal derivative moments distribution

$$E_1/E_2 = 6.7, \ell_1/\ell_2 = 1$$

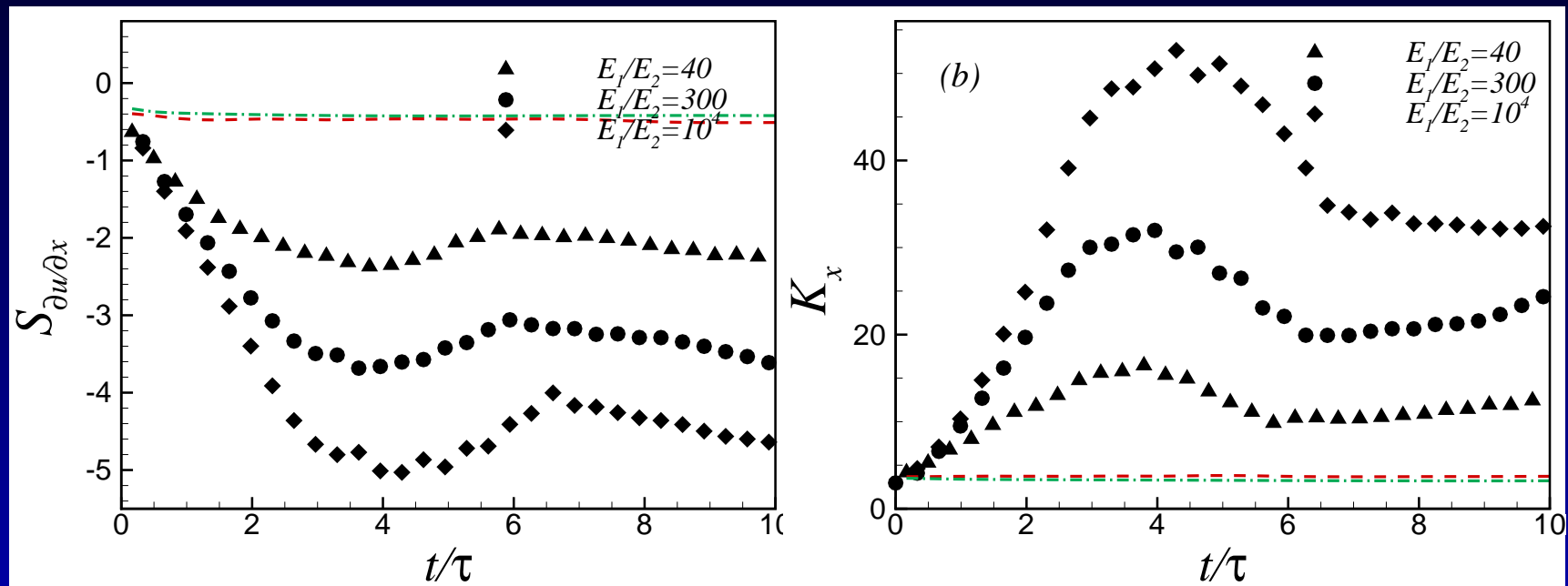


η is the dimensionless coordinate along the mixing
 Δ is the mixing half-width



Mixing: Longitudinal derivatives

Time evolution of the peak of the derivative statistics



u = velocity component in the mixing direction

x = direction along the mixing

τ = initial eddy turnover time

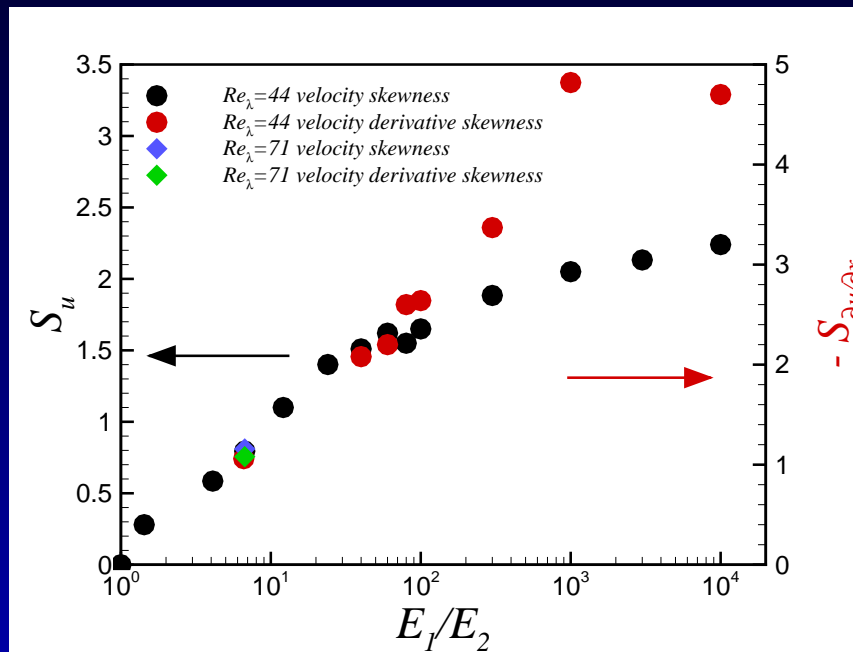
— — — high energy homogeneous region

— . — . — low energy homogeneous region

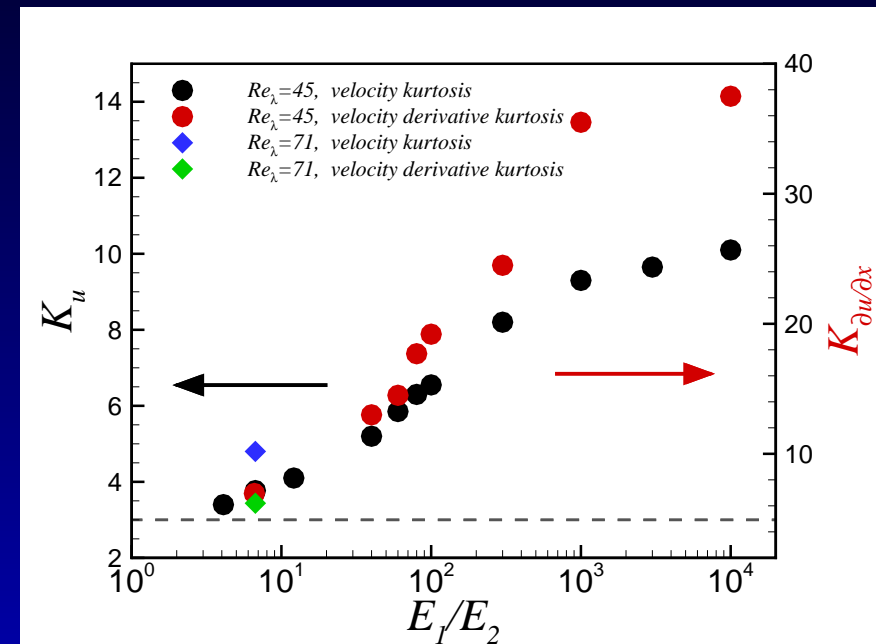


Asymptote for $E_1/E_2 \rightarrow +\infty$

Velocity Skewness



Velocity Kurtosis

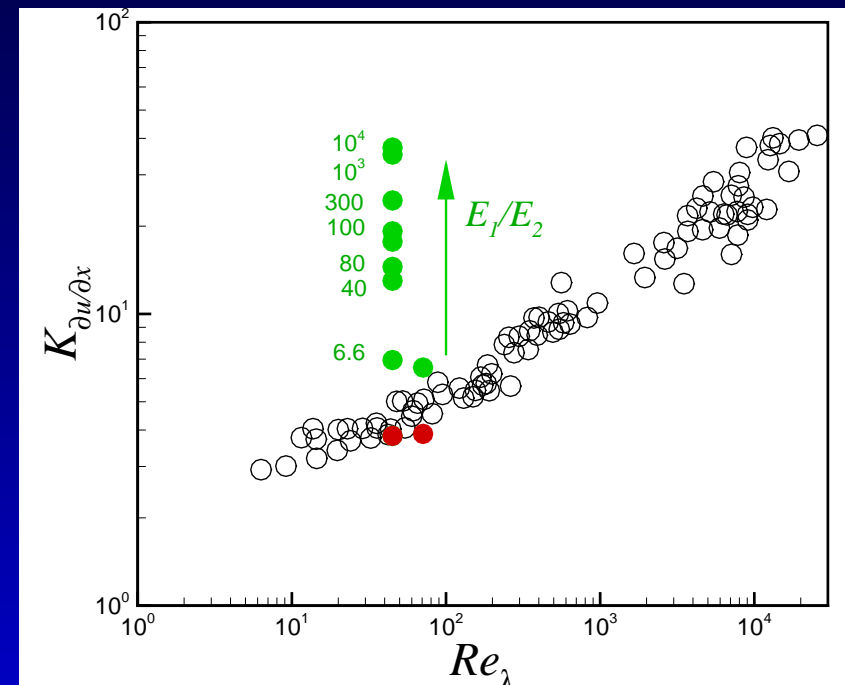
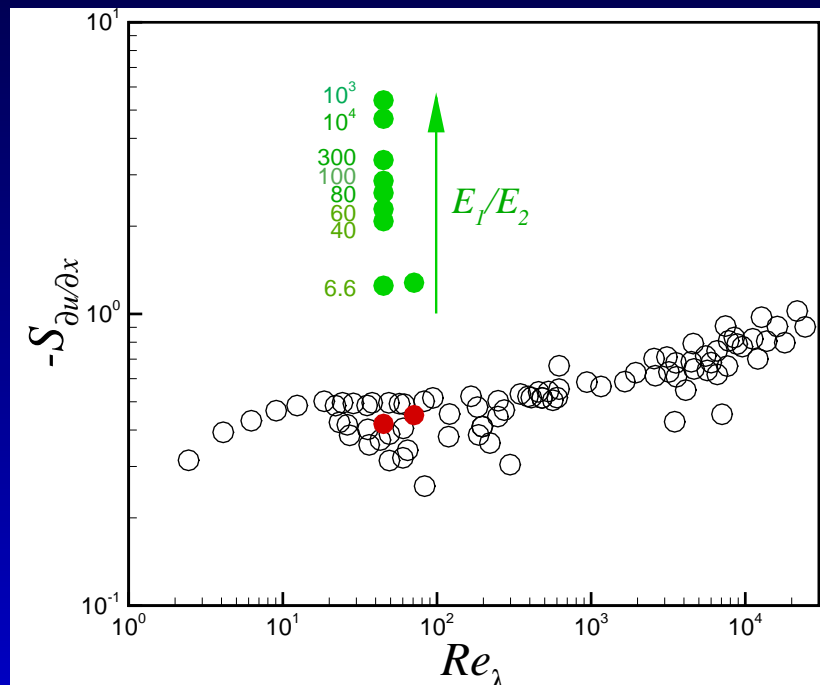


Longitudinal derivative Skewness and Kurtosis of the velocity component along the mixing direction



Comparison with homogeneous turbulence

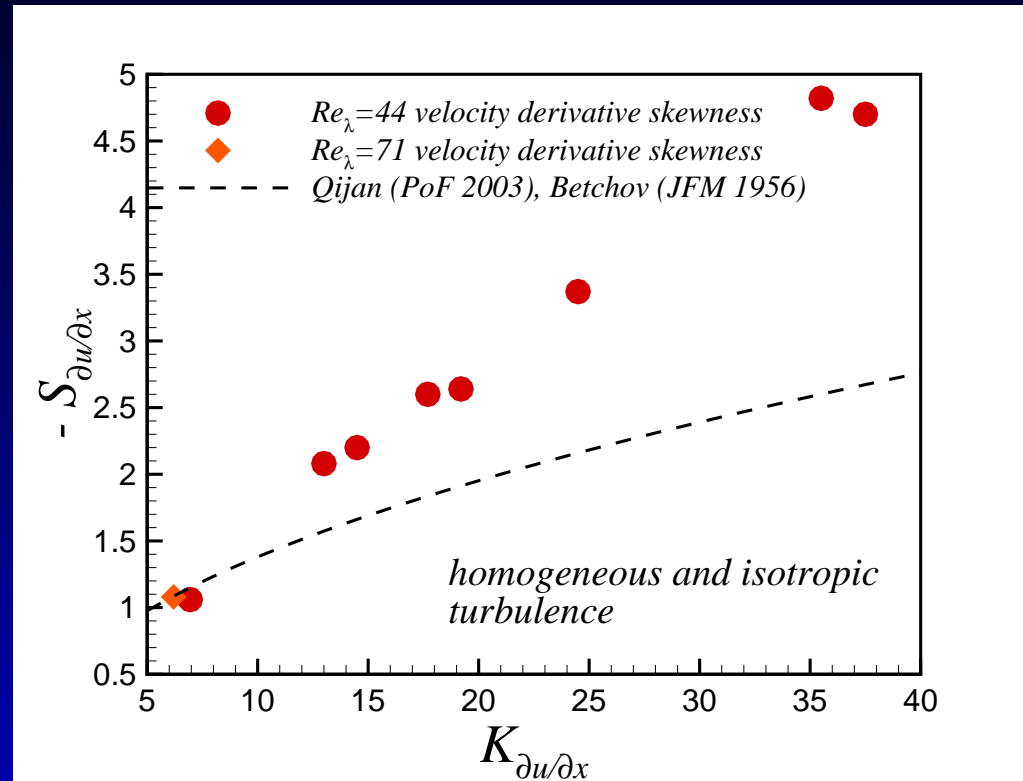
Comparison of longitudinal moments inside the mixing with longitudinal moments in homogeneous and isotropic turbulence (data from Sreenivasan and Antonia, *Ann.Rev.Fluid Mech* 1997)



- HIT, present simulations
- Shearless mixings, present simulations
- Homogeneous turbulence



Comparison with homogeneous turbulence (II)



Comparison with the upper bound

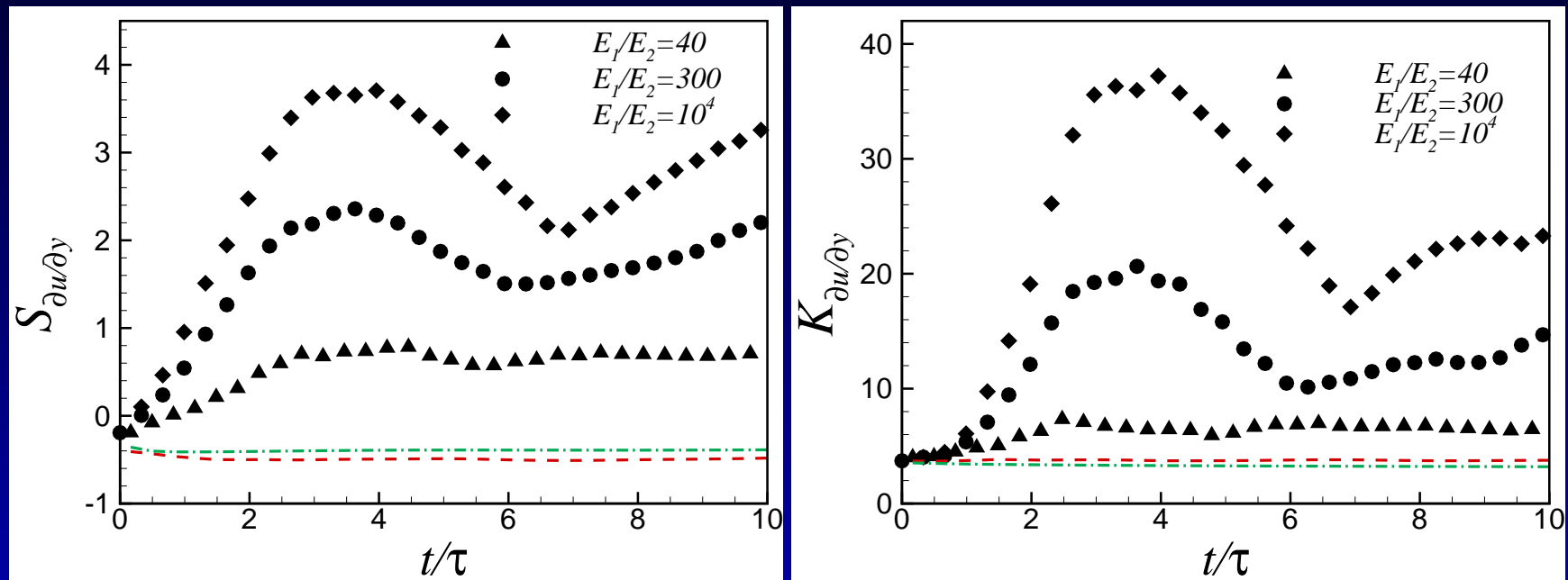
$$-S_{\partial u/\partial x} \leq 2 \left(\frac{K_{\partial u/\partial x}}{21} \right)^{\frac{1}{2}}$$

of the longitudinal skewness in homogeneous turbulence



Mixing: Transversal derivatives

Time evolution of the peak of the derivative statistics



u = velocity component in the mixing direction

y = direction normal to the mixing

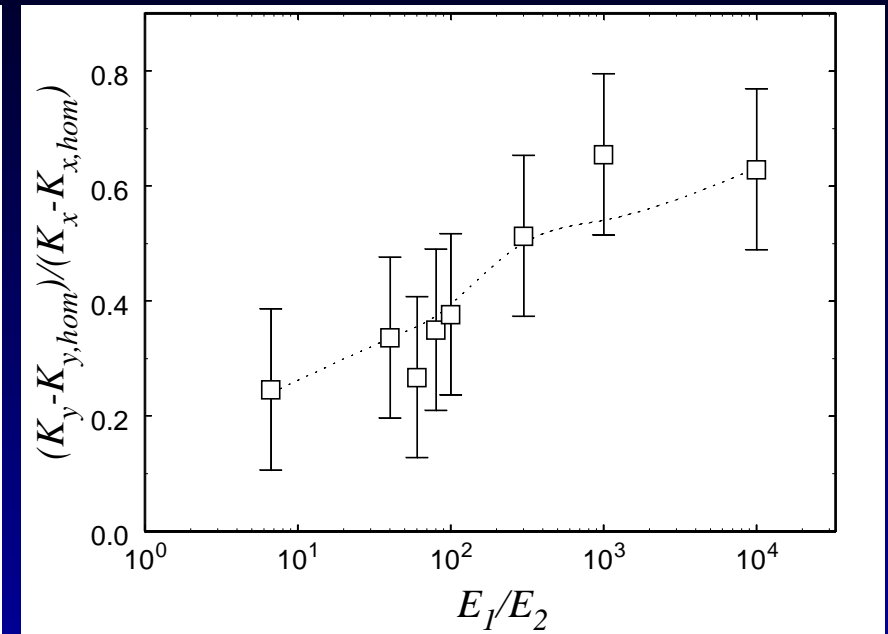
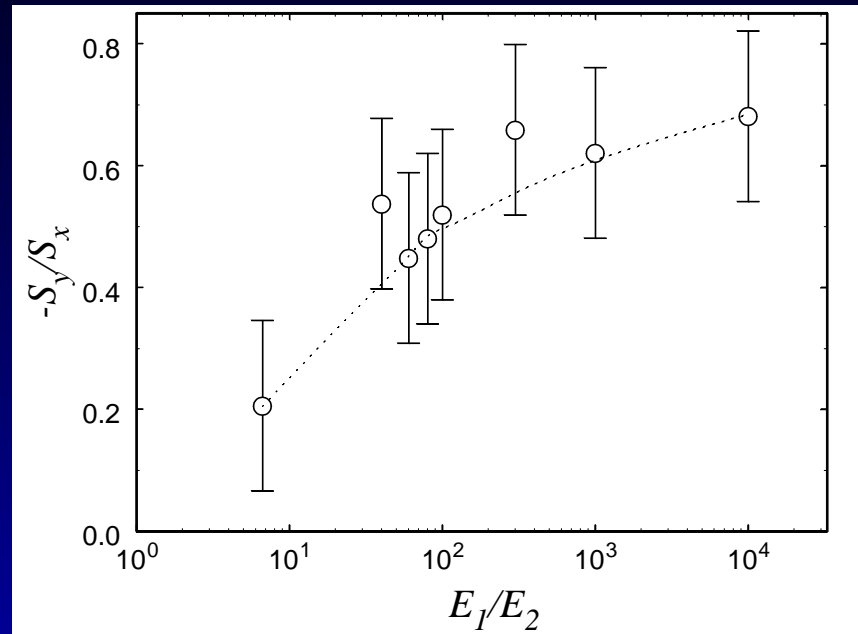
τ = initial eddy turnover time

— — — — high energy homogeneous region

— . — . — low energy homogeneous region



Small scale anisotropy: uniform integral scale



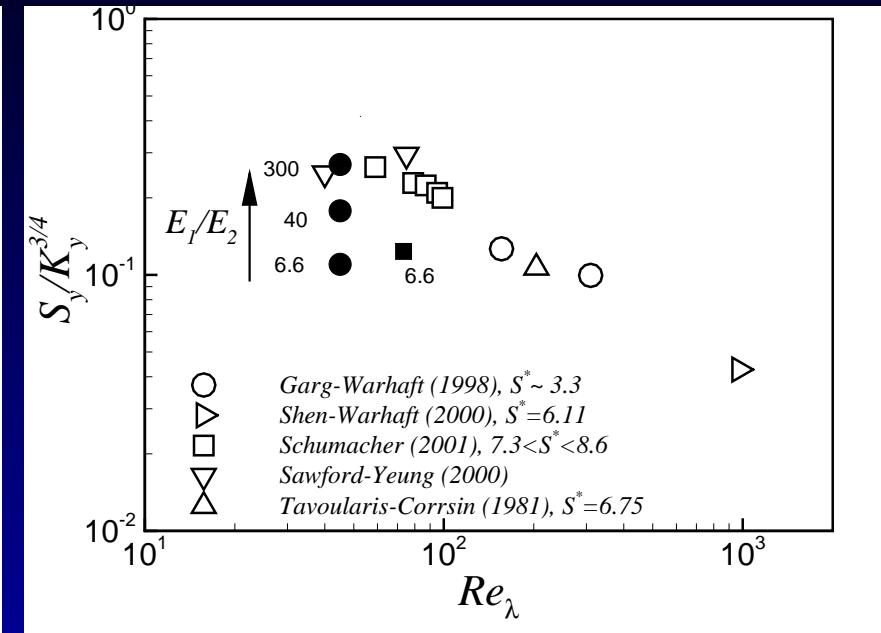
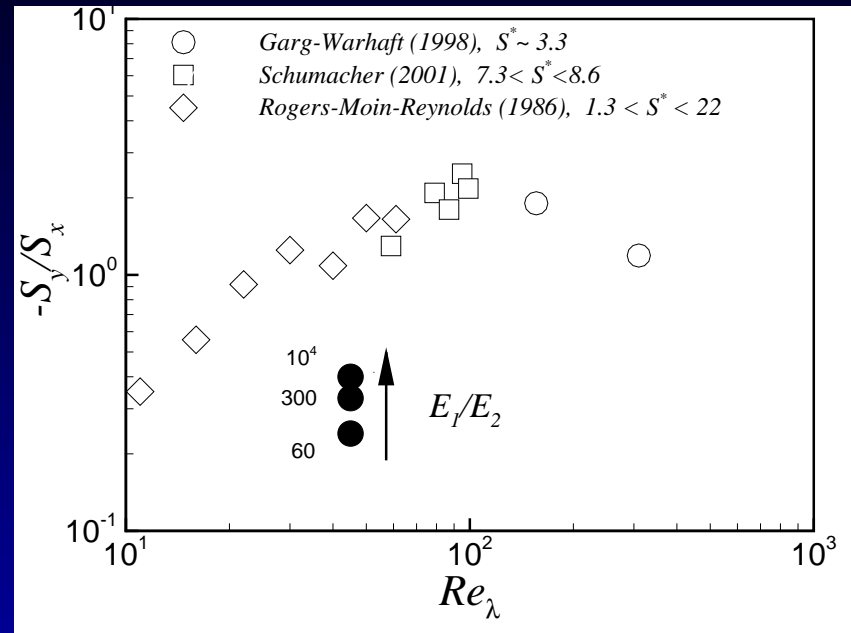
(a) isotropy of the derivative skewness;

(b) isotropy of the derivative kurtosis.

The bars represent the amplitude of the fluctuations of these ratios.



Comparison with homogenous shear turbulence

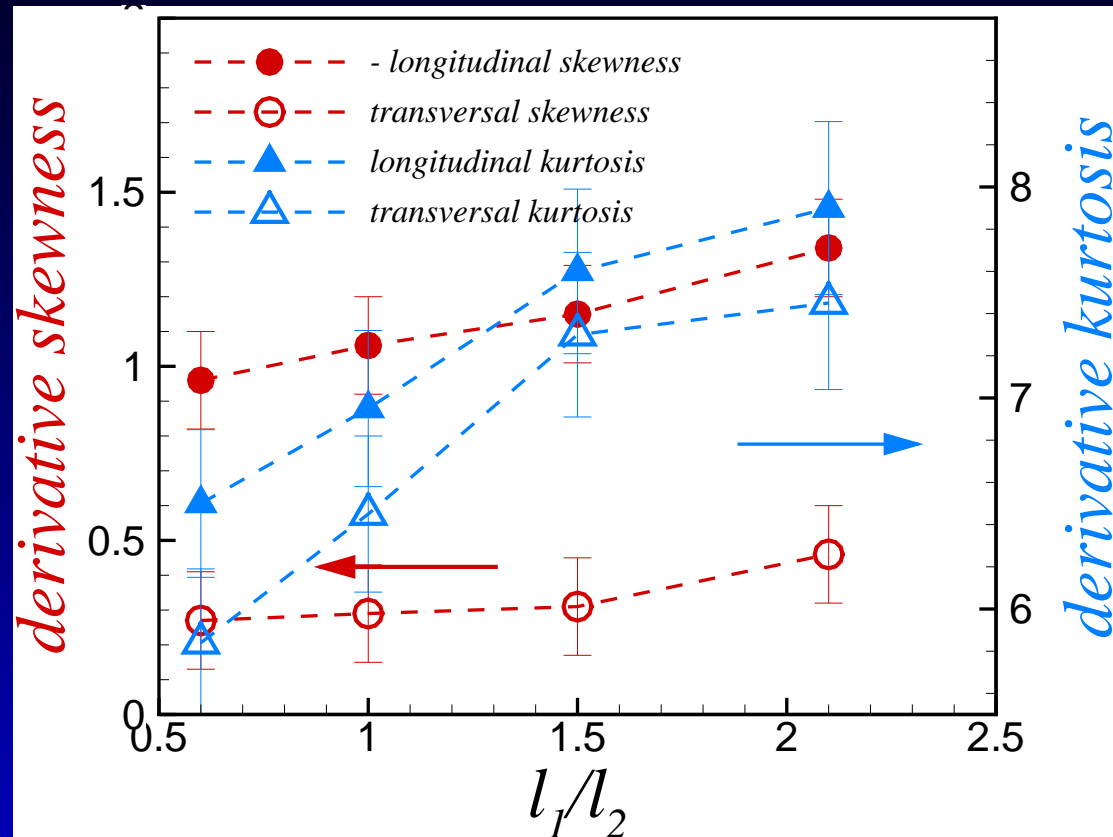


Comparison of anisotropy and intermittency:

- shearless mixing data, \bullet $Re_\lambda = 45$, \square $Re_\lambda = 71$
- empty symbols: homogeneous shear flows data.



Derivative statistics: non uniform integral scale



Conclusions

Direct numerical simulations carried over a large range of turbulent energy ratios ($6 \leq \mathcal{E} \leq 10^4$) show:

- a high level of intermittency, comparable with that of shear flows, on longitudinal and transversal derivative moments
- anisotropy of third and fourth order derivative moments increasing with the energy ratio E_1/E_2 .
- a minor influence of the gradient of integral scale on the derivative statistics (small scales) than on the velocity statistics (large and inertial scales)



Conclusions

Direct numerical simulations carried over a large range of turbulent energy ratios ($6 \leq \mathcal{E} \leq 10^4$) show:

- a high level of intermittency, comparable with that of shear flows, on longitudinal and transversal derivative moments
- anisotropy of third and fourth order derivative moments increasing with the energy ratio E_1/E_2 .
- *Future work*
- higher Reynolds number
- study of the mixing where the initial nonhomogeneity is associated to the integral scale variation only



Appendix: Shearless mixing statistics

	$\overline{u_i u_i u_3} / \overline{u_3^2}^{3/2}$			Velocity Kurtosis			Long. derivative skewness			Long. derivative kurtosis			Trans. Moments	
	i=1	i=2	i=3	K_{u_1}	K_{u_2}	K_{u_3}	$S_{\partial_1 u_1}$	$S_{\partial_2 u_2}$	$S_{\partial_3 u_3}$	$K_{\partial_1 u_1}$	$K_{\partial_2 u_2}$	$K_{\partial_3 u_3}$	$S_{\partial_1 u_3}$	$K_{\partial_1 u_3}$
$E_1/E_2 :$	Mixings with $\ell_1/\ell_2 = 1, R_\lambda = 45$													
6.6	0.34	0.36	0.82	3.6	3.4	4.07	-0.11	-0.10	-1.06	5.0	4.85	6.95	0.29	6.55
40	0.54	0.59	1.34	5.6	6.0	5.56	0.55	0.80	-2.08	7.1	6.77	13.0	0.50	8.50
80	0.63	0.69	1.57	6.4	6.7	6.67	0.95	1.1	-2.60	8.5	8.6	17.7	0.60	13.0
300	0.78	0.87	1.91	7.5	8.2	8.93	1.5	2.0	-3.37	16	14	24.5	1.0	13.6
10e4	0.92	0.95	2.20	7.8	8.2	11.6	3.4	3.2	-4.70	20	26	37.3	1.05	23.1
$\ell_1/\ell_2 :$	Mixings with $E_1/E_2 \approx 6.6, R_\lambda = 45$													
0.6	0.32	0.33	0.77	3.45	3.4	3.85	-0.14	-0.10	-0.94	5.0	4.8	6.50	0.27	5.90
6.6	0.34	0.36	0.82	3.6	3.4	4.07	-0.11	-0.10	-1.06	5.0	4.85	6.95	0.29	6.55
1.5	0.49	0.52	1.20	4.0	3.6	5.5	-0.12	-0.08	-1.14	5.2	4.9	7.60	0.31	7.70
2.1	0.55	0.58	1.40	4.9	4.4	7.5	-0.05	-0.02	-1.34	5.2	5.0	7.80	0.46	8.22
Mixings with $E_1/E_2 = 6.7, \ell_1/\ell_2 = 1, R_\lambda = 71$														
	0.42	0.37	0.81	3.65	3.55	4.8	-0.15	-0.19	-1.08	4.45	4.65	6.20	0.30	5.95
Veeravalli and Warhaft(1989), $E_1/E_2 \approx 7, \ell_1/\ell_2 \approx 1.5 \div 1.7$														
bars	==	==	1.06	4.36	4.23	5.53	==	==	==	==	==	==	=	=
plate	==	==	0.63	3.47	3.49	4.07	==	==	==	==	==	==	=	=

Legend:

3 = inhomogeneous direction

1,2 = homogeneous directions

S_{u_i}, K_{u_i} = skewness and kurtosis of u_i

$S_{\partial_j u_i}, K_{\partial_j u_i}$ = skewness and kurtosis of $\partial u_i / \partial x_j$



Appendix: homogeneous shear turbulence

Homogeneous shear turbulence						Shearless mixings							
Re_λ	S^*	Sd-lg	Kd-lg	Sd-tr	Kd-tr	Re_λ	E_1/E_2	ℓ_1/ℓ_2	Sd-lg	Kd-lg	Sd-tr	Kd-tr	
Garg-Warhaft 1998													
156	3.39	-0.42	7.1	0.8	11.7								
310	3.31	-0.42	6.9	0.5	8.6								
Shen-Warhaft 2000													
974	6.11	=	=	0.24	*10								
Gylfason-Warhaft 2004													
452	=	-0.546	9.94	=	=								
877	=	-0.586	13.1	=	=								
Schumacher 2001													
59	7.32	-0.74	6.3	0.96	5.6	45	6.6	1.0	-1.06	6.95	0.29	6.55	
79	8.18	-0.44	4.8	0.92	6.4	71	6.6	1.0	-1.08	6.25	0.30	5.95	
87	8.58	-0.50	5.3	0.90	6.4	45	40	1.0	-2.08	13.0	0.50	8.50	
95	8.22	-0.37	4.3	0.92	7.2	45	300	1.0	-2.60	17.7	0.60	13.0	
99	8.37	-0.40	5.0	0.87	7.1	45	10^4	1.0	-3.37	24.5	1.0	13.6	
Rogers-Moin-Reynolds 1986													
11	1.3	-1.2	=	0.42	=	45	6.5	0.6	-0.94	6.50	0.27	5.90	
16	3.3	-0.95	=	0.53	=	45	6.7	1.5	-1.24	7.60	0.31	7.70	
22	6.2	-0.61	=	0.56	=	45	6.7	2.1	-1.34	7.80	0.46	8.22	
30	10	-0.48	=	0.60	=								
40	14	-0.58	=	0.63	=								
50	19	-0.42	=	0.70	=								
61	22	-0.43	=	0.71	=								
Sawford-Yeung 2000													
40	=	=	=	0.92	*5.7								
75	=	=	=	1.20	*6.5								
Tavoularis-Corrsin 1981													
204	6.75	=	=	*0.6	*10								

Legend:

$$S^* = S \langle u^2 \rangle / \epsilon$$

dimensionless shear
parameter

Sd = derivative skewness,

Kd = derivative kurtosis,

tr = transversal,

lg = longitudinal

